IAC E4.3A.3

" TSS 1 -- THE "TETHERED" SATELLITE DEPLOYED FROM THE SPACE SHUTTLE "

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The concept of "tethered satellite i.e. a satellite connected by a cable to the Shuttle was born in the italic genius mind of Prof. Giuseppe Colombo of Padoa University, big expert of celestial mechanics , who were also working for Harvard Smithsonian Center in Cambridge, Massachusetts. Prof. Colombo obtained a great success in NASA for his studies on Mercury and the mission orbits of the american space probe Mariner 10, launched towards that planet, the nearest to the Sun in our solar systems.

The original idea really started from another italian professor ,Prof. Mario Grossi radio-physic at the Harvard Smithsonian Center for Astrophisics, who proposed to NASA in 1972 the development of a big spatial antenna for very low frequency communications.

This antenna was consisting of a conducting aluminum cable of few millimeters diameter but as long as 20 km till 100 km.

Prof. Grossi was able to involve the Padoa collegue in the research but Prof. Colombo developed the concept in a different manner and convinced NASA and CNR, that was managing the National Space Plan, the initial embryon from which born the Italian Space Agency, to develop it.

In 1984 the two agencies signed in Rome a Memorandum of Understanding for starting a bilateral programme in which NASA would be responsible of the launch and the global system, whose part on board of the Shuttle (the release mechanisms and cable retrieval) was under the responsibility of american Martin Marietta in Denver, Colorado while the satellite part , wire appended and with all the scientific experiment on board, was under italian responsibility (Aeritalia in Turin).

Prof. Colombo was also able to convince many key persons such as James Begg, the current NASA Administrator , and the american scientist Nobie Stone while in Italy prof. Luciano Guerriero, CNR National Space Plan director, and prof. Ernesto Vallerani , Aeritalia Space Systems Group director, showing that it is possible to descend from Space Shuttle a satellite appended to a cable of 20 km length and more till to 100 km, for studying and analyzing the Earth atmosphere between 100 and 200 km height.

This is not possible to perform with missiles that will return to the Earth with a ballistic trajectory, because the orbit is too low for allowing flights longer than some days or passing throu these layers only in the atmosphere reentry.

The Shuttle orbit at about three hundred km of height was the best for this kind of

experimental research. Moreover the wire and the related circuitry should act as a spire passing in the terrestrial magnetic field then generating induced current and then charges moving in the wire (electrodynamic mission).

In 1985 a bilateral group of scientists was formed with the specific job of proposing experiments to be carried out on the italian satellite.

Coordinators of this Investigator Working Group (IWG) were Prof. Marino Dobrowolny of the CNR Institute for Space interplanetary Phisics and Prof.Nobie Stone for the American side.

This group selected then twelve experiments to be carried into the satellite, among them Dobrowolny's RETE, Mariani's TEMAG and Stone's ROPE that had to measure the interactive relationships between satellite itself and plasma surrounding satellite (RETE and ROPE) and the magnetic environment around satellite (TEMAG). The satellite then received two arms : one with ROPE's sensor and the magnetometer and the other the S band antenna.

Other scientific experiments were concerning the basic experiment, the electrodynamic one of Prof. Bonifazi, represented by the" Core equipment " on board of the satellite as well as other components on the Shuttle cargo bay, that had to make an electrical circuit between Earth and satellite from one side represented by the conductive wire and from the other side the electrons flux emitted by an electronic gun.

The first mission of Thetered Satellite System (TSS) was then the electrodynamic one, during which the experiment will be the production of current into space, flowing throu the cable and then measured from the on board instrumentation.

The cable, supposed to not experience any tension load, even if the satellite and Shuttle would fly into two different orbits with the height difference of twenty km equivalent to the wire length itself, was designed with a diameter of 2.54 mm.with a core of Nomex surrounded by ten copper wires of 0.16 mm in which the current had to flow and a Kevlar sheath, all externally covered by a Nomex skirt. The whole cable of 20 km was not exceeding 8 kg mass.

The release mechanisms was complex : a tower extending for 12 meters from the Shuttle cargo-bay with on top a canister containing the satellite to be released has been designed. Once the tower was completely extended, a command had to open the mechanical interfaces between satellite and canister and the satellite would leave the tower with a speed of about 2 meter per second, taking with it the wire into the free space.

The satellite, designed by Alenia Spazio in Turin, had a difficult starting that strongly experienced the capabilities of a great number of engineers, technicians and consultants required to reinforce the scientific satellites group just formed under the responsibility of Dr.Bevilacqua. In fact in 1982/83 the Space System Group, now under the full responsibility of prof. Vallerani , was divided into two groups: one for scientific satellites and the second dedicated to space transportation systems under Mr. Piantella responsibility.

After a series of changes, the program management responsibility was given to Ing. Tornani that performed well overcoming the initial difficulties and leaving the program later on , for health reason , in the hands of Ing. Bruno Strim that completed it , has already done successfully with the Hipparcos satellite , an European scientific satellite in cooperation with French Matra company.

From the ASI side the program was managed by Ing. Gianfranco Manarini, open mind man , well helpful to collaborate with industry , in trouble for the technical problems encountered during this complex satellite design.

The biggest problem was consisting in the understanding of the basic dynamic of the body appended to the cable to be extended into space and then returned to the Shuttle as a dog when the owner pulls the lead. It has been necessary many months for understanding the physics and prepare the simulations for the behavior of the satellite and then develop the detailed design ; if I remind well, a big help came from Prof. Bergamaschi , Padoa University , who was the sole man understanding the fundamental problems of yo-yo movement (but not so similar) when the satellite was recalled.

Finally the satellite came as a sphere of 1.6 m diameter and of about 500 kg mass, divided into three parts : the superior compartment had the scientific instrumentation (around 70 kg) and the lower compartment was also divided into two parts.

In this compartment the upper part near to the maximum circumference was occupied by the on board propulsion system , that had to push the satellite during the releasing phase (and in the opposite direction but with completely different laws during the recovery phase) in addition to contribute to the general stabilization and the pointing attitude control by means of various sensors, while in the lower part there was the service module with on board subsystems from the electrical power supply , the attitude control computer , the data handler for elaborating and transmitting the scientific data as well as the housekeeping.

Another problem came also from the white paint selected for its low thermooptical properties to lower the solar heat absorption, to isolate the inner part of the satellite, and in the mean time have a great surface electrical conduction for allowing the reception and distribution of the electrical charges to be collected.

This paint was initially provided from NASA throu GSFC but later on, one month before launch , NASA imposed the paint produced by MSFC that had better performance (compelling Aeritalia to paint new structural elements and substitute them with the parts already installed on the satellite).

Another challenge won by italian engineers was the design of the electronic gun, for Aeritalia's responsibility "core equipment" preparation , made by Proel company in Florence, consisting of two electrons generator (one as spare) of 1 ampere power; the basic idea was that the electrons were going to the Earth pole and then return to the satellite and, throughout the conductive cable, reach the generator thus closing the circuit. Laben company in Milan had to design and develop the data handler for the satellite-Earth data exchange .

THE FIRST MISSION

The satellite performed a series of tests both in Turin Aeritalia premises and the final thermal vacuum test in Germany Ottobrunn IABG premises and then was finally consigned to ASI and later on delivered to NASA , that in June 1992 started the on line integration activities with the Shuttle and the other mission payloads.

At the end of July, after the last controls and the Tethered primary batteries charging, that will provide power just for fourty days, the Space Shuttle was ready to be launched in July 31st 1992.

The first Italian astronaut Ing. Franco Malerba was on board among the crew ;

he was able to fly for the bilateral agreement NASA/ASI after having overcome a series of typical italian troubles , lasted at least ten years after his participation to Italian astronaut selection.

The Shuttle mission was also foreseeing the on orbit deployment of european platform “Eureca” (standing for European Retrievable Carrier) left in space with a series of scientific instruments and to be recovered within a year and carried on ground always from Shuttle. Aeritalia was responsible of the carbon fiber structure design and manufacturing for this platform.

The tethered satellite mission was not successful as expected : the satellite was released only for 256 m.(on ground it was discovered that this came for a protrusion of a bolt in the main structure of the release mechanism , I believe, not well controlled by Martin Marietta,that , causing friction on the cable , was not allowing the correct release movement, in spite of the functional test done on the satellite (?).

From the electrodynamic standpoint the first mission was positive, notwithstanding the limited lenght of released wire, because a current of few milliampere was generated.

NASA , after the necessary ground investigations, understood the mistake (as usual the controls on the foreign were too severe in relationships with the control of American suppliers).

As an example I remind that to the various Tethered reviews many tenths of NASA and NASA subcontractors that were also theyr consultants (and this not only for Tethered project but also for other programs).Those people were controlling all our reports from all standpoints, from the technical to the “safety” one and were not hesitating to issue any type of comment , compelling us to remake or deepen works and analyses on questions not well convincing them , while they were less severe in front of American companies.

I believe that from the manufacturing drawings, to be controlled for giving the authorization to proceed, the Tethered problem was already evident as well as latter on from the functional tests, if carefully conducted; for this reason NASA was allowing to go on with a reflight mission of the satellite , that had to be slightly modified.

THE SECOND MISSION (REFLIGHT MISSION)

With the modifications developed by Aeritalia to the attitude control and those by Martin Marietta to the release/retrieval mechanism, we reach 1996 when the satellite came back in USA for the final integration with Shuttle.

In this event in the crew of STS 75 mission was included the italian astronaut Umberto Guidoni , who four years before acted as back up of mr.Malerba in the previous mission.In this mission crew there was another Italian , Mr Maurizio Cheli , test pilot in Aeritalia, selected as astronaut in the group of ESA.

The mission was going well : once in orbit the tower with the satellite on top reached its maximum extension and the satellite was carefully released step by step till 19.9 km of length but then the cable did break-up and the satellite flew into deep space , with big dismay of the crew as well as of the public following the event.

The explanation was not simple but the records were showing the current flowing in the wire without any problem till a certain point in which a probable defect in the wire created an increase of resistance and then a short circuit that burned out the cable breaking it (NASA was not thinking to use a new cable in respect to the “ old” one already flown four years before,

neither was controlled before and later with a simple continuity test…….. (?).

The satellite was visible for long time mainly for the lenght of the cable , reflecting the sun light, and reentered in the atmosphere three days latter self destroying.

The short satellite operating life in this reflight mission allowed many verifications on main scientific questions at the base of the mission. In any case the cost of the mission , of many hundred millions of dollars, even if subdivided between NASA and ASI,was high enough for not proceeding on with other kind of mission, also more complex, already planned.

From a preliminary estimate the first flight was costing around two hundred and fifty millions of dollars subdivided between NASA and ASI (the satellite value was around 75/80 millions of dollars and the Proel electron guns 25/30 millions of dollars in addition to ground tests and the launch preparation 25/30 millions of dollars) while the second flight was costing other one hundred and fifty millions , perhaps a not cheap price for verifying some theoretical physics principles.

THE FOLLOW ON

The theoretical studies and the results obtained demonstrated the feasibility of a " space lift" of gravitational type, i.e. a system with a platform capable to move along a cable and reach different eights for organizing experiments at different microgravitational values as well as supply power throu wire to a future space station orbiting around the Earth.

For many years the concept of a tethered satellite was developed in USA by Proffs Robert Forward and Robert Hoyt who founded the company " Tethered Unlimited Inc." in various applications, one among which considering the possibility to deliver payloads from LEO to cislunar orbits and more (MERITT project standing for MARS Earth Rapid Interplanetary Tether Transport) all based on on tethered cables.

Also Dr. Les Johnson , scientist at Marshall Space Flight Center was considering for long time the potential of tether as propulsion system and organized some experiments called " ProSEDS " for Propulsive Small Expendable Deployer System i.e. a system for tether propulsion installed on top of a Delta 2 launcher.

As responsible of the advanced study group in Alenia since 1992, I was trying to not loose this specific experience in our company and I developed some of these studies with small internal funds. Specifically I supported for some years the EDOARD project standing for Electrodynamic De-Orbiting and Re-entry Device, i.e. a tethered system for deorbiting on end of life or in case of failures of the satellite, from an idea of prof.Luciano Iess and Claudio Bruno of Space Department in Engineering Roma University " La Sapienza " and developed by Turin Alenia Space..

Surely it would be necessary the open mind and admirable fantasy of a person such as was Prof. Colombo, who any time coming in Aeritalia entertained with his jokes but also whipped us, young engineers, with a lot of very complicated physical problems, showing in any case an advanced vision of space applications.

In Padoa University CISAS (Center of Studies and Activities for Space) has been named to him and in 1994, after ten years from his death, has organized an international congress in which the "Ideas for space research after 2000 " have been discussed starting from the perspectives opened by him.

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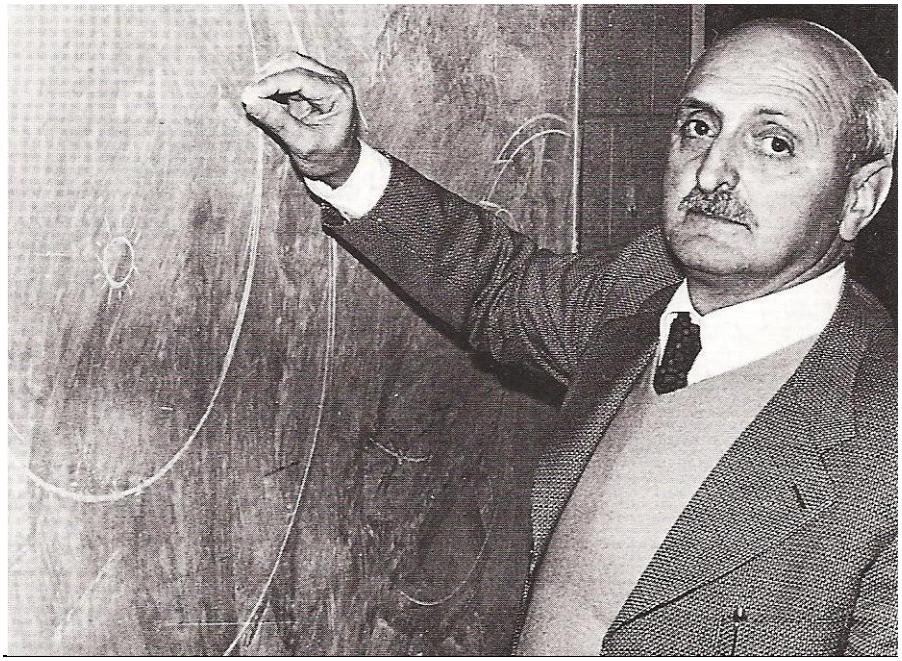


Fig 1 Prof. Colombo teaching in University

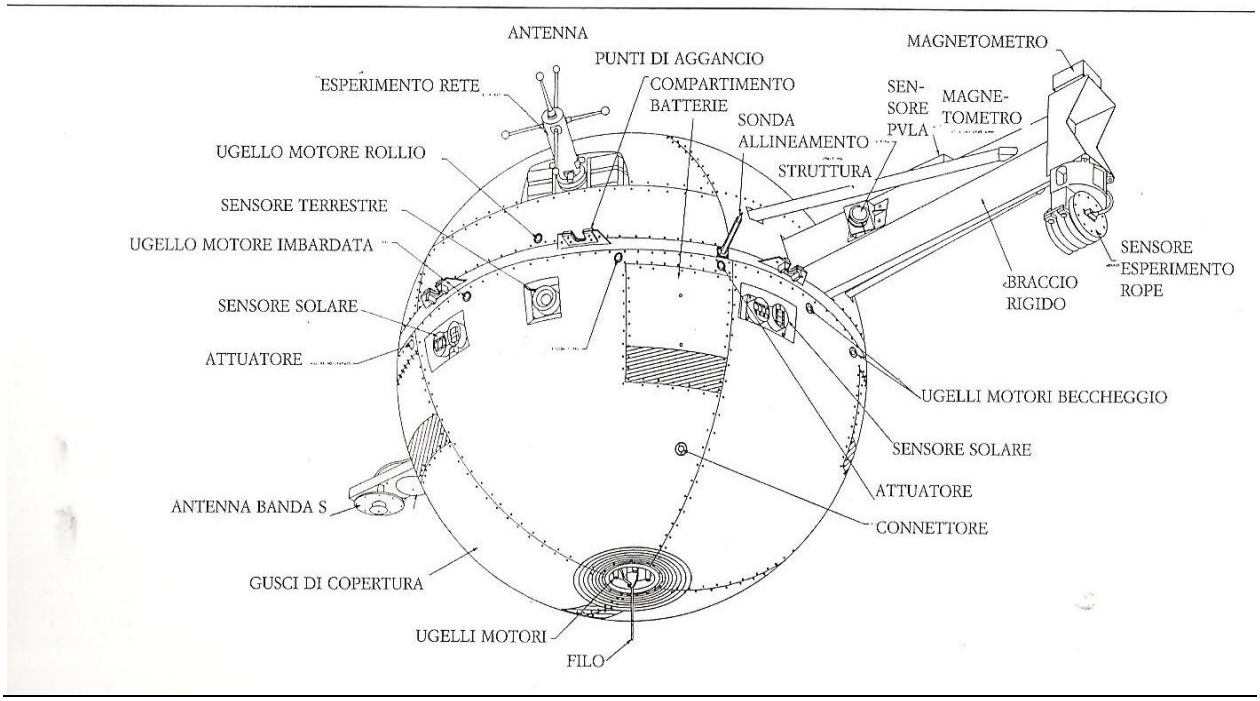


Fig. 2 Figure of the overall satellite with explanations

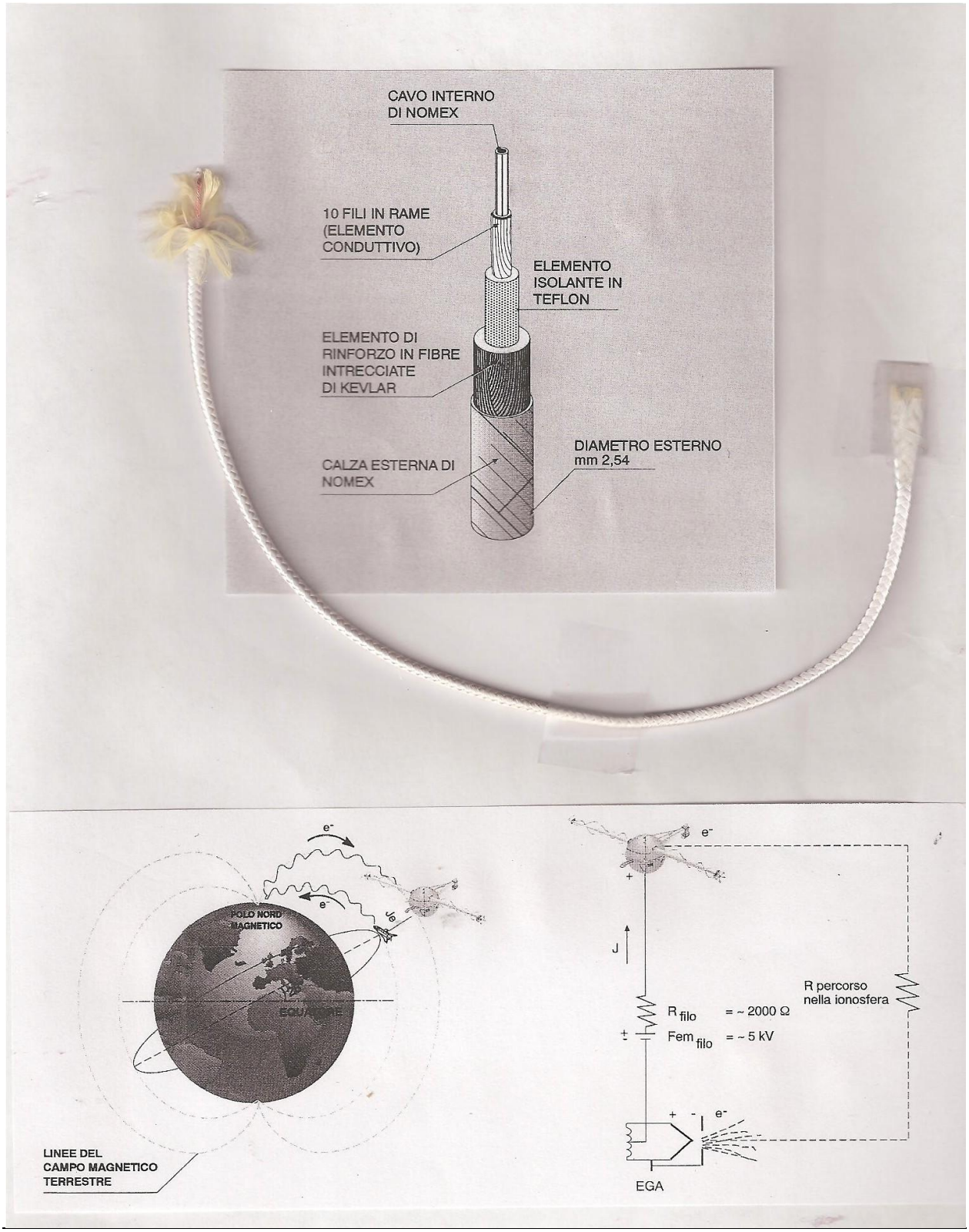


Fig. 3 Sample of tethered satellite cable with section and overall scheme

Fig. 4 Tethered satellite mission attraversing Earth's magnetic field.

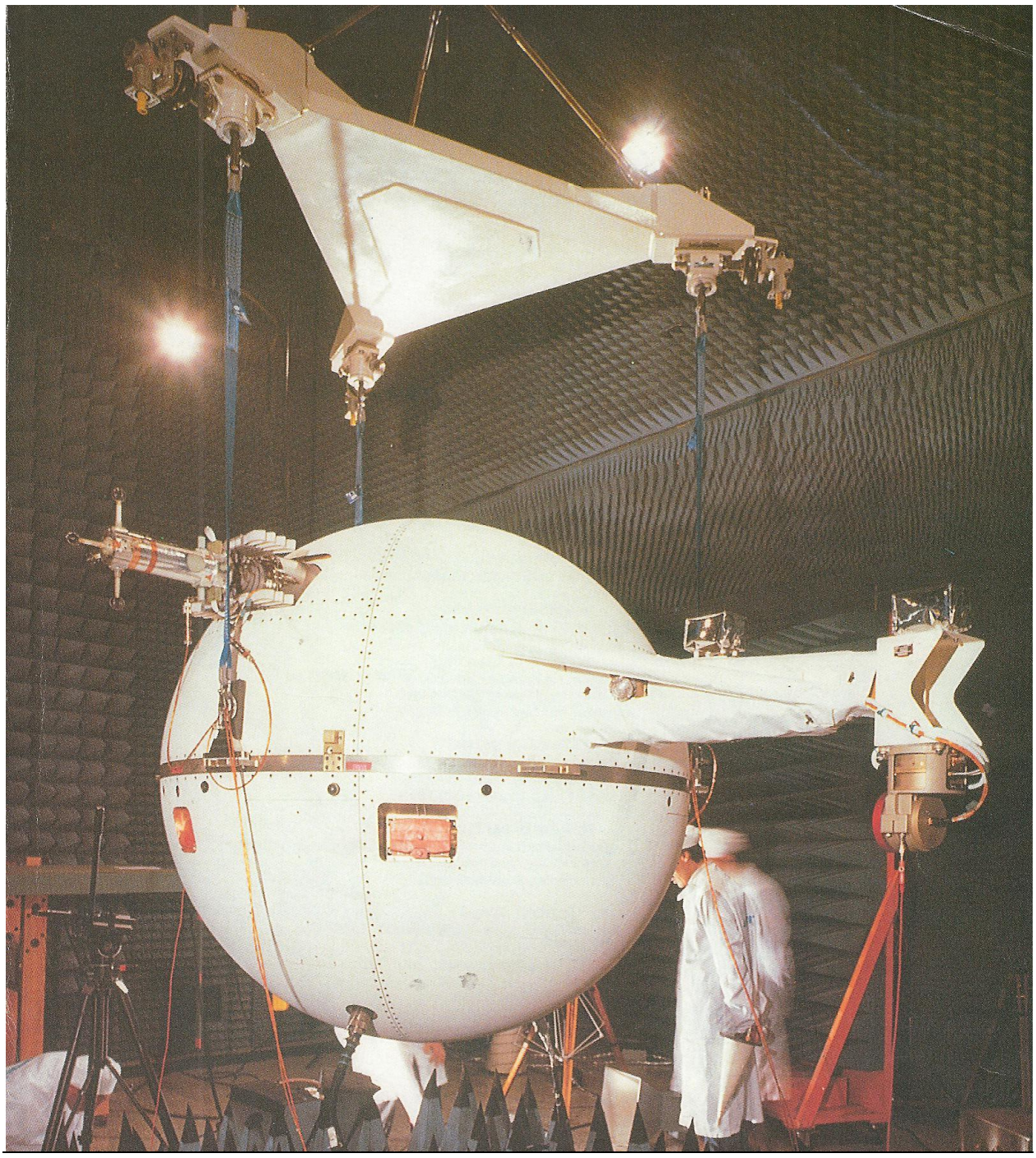
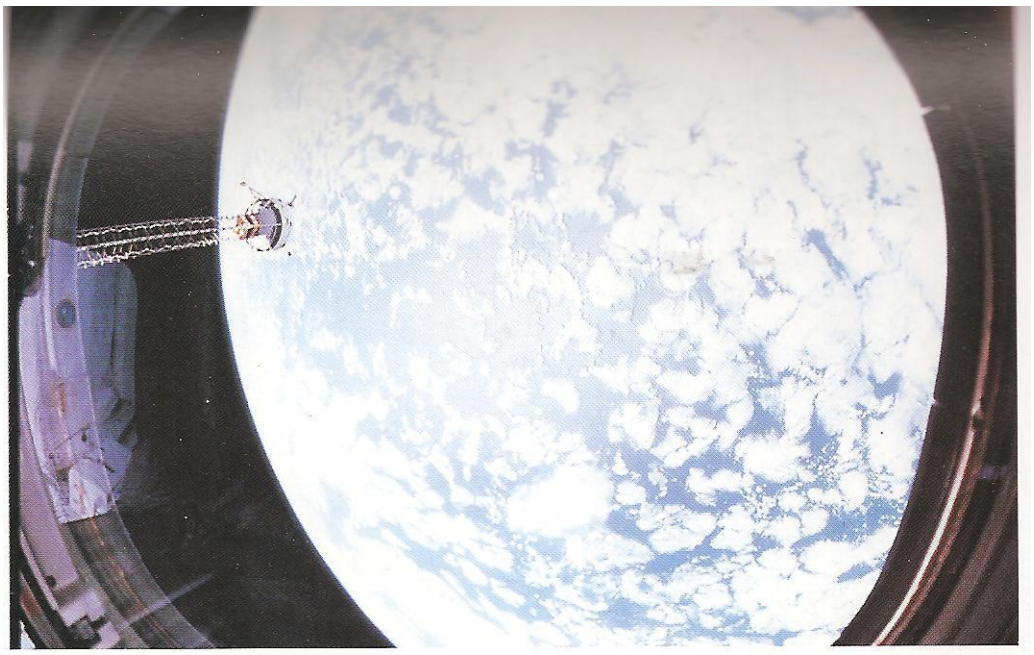
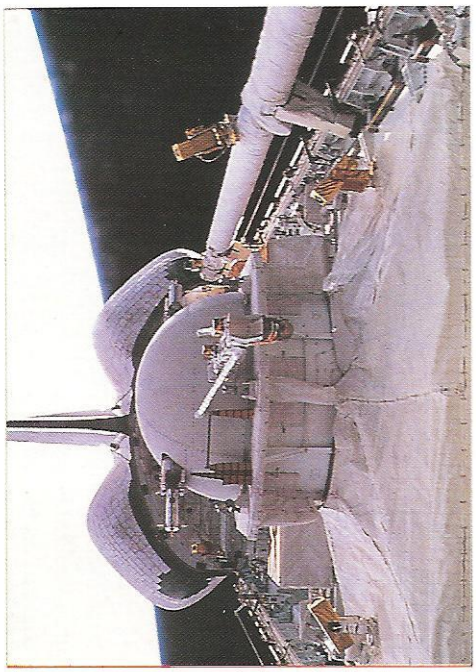


Fig. 4 Tethered satellite in acoustic test bay





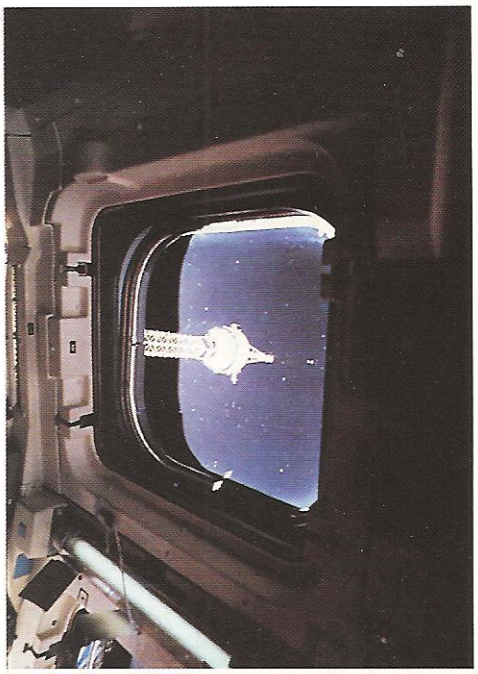


Fig 5 Three views of Tethered satellite into the Shuttle cargo bay,

On top of the deployed tower and seen by the crew of the Shuttle.

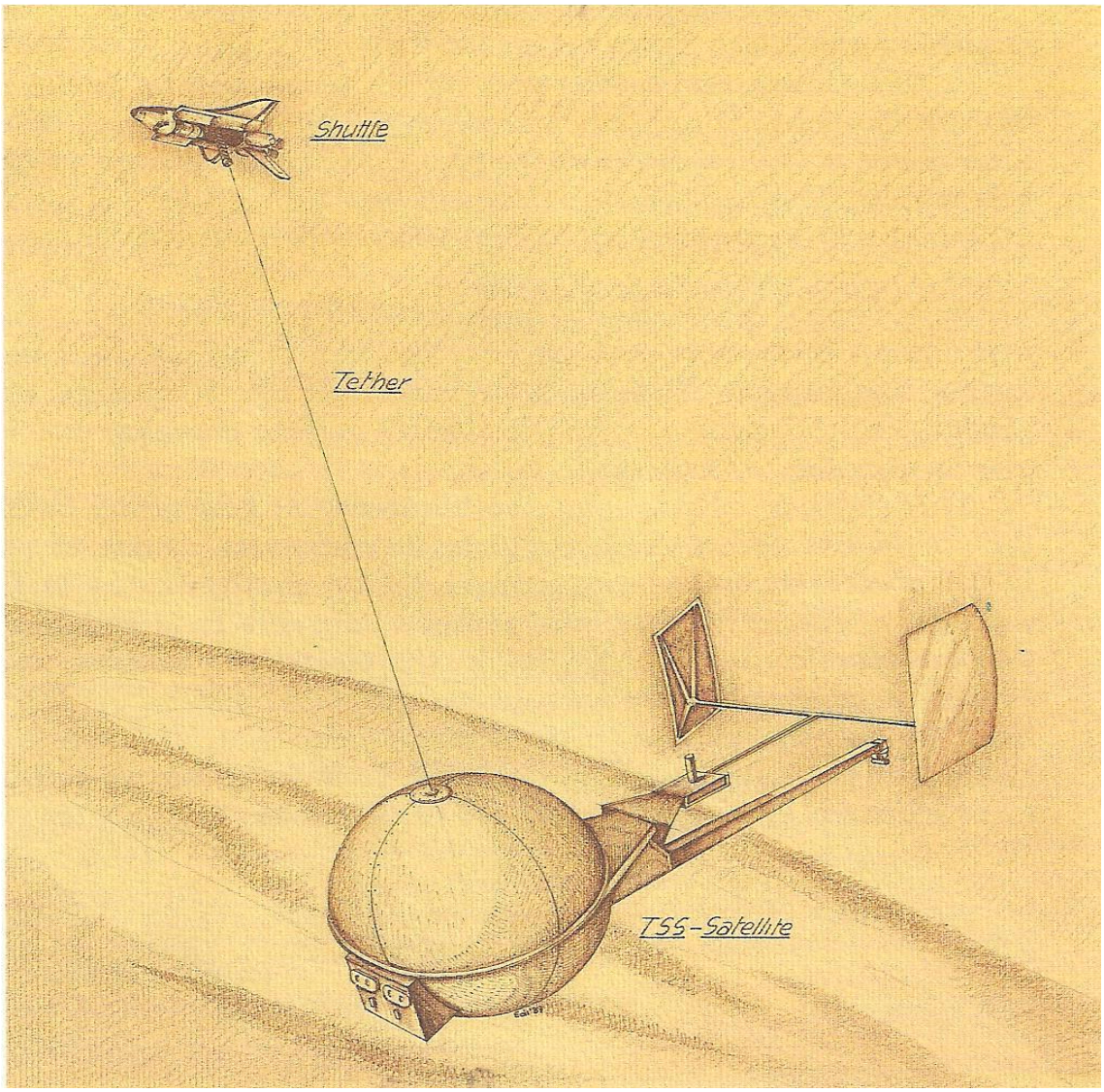


Fig 6 The atmospheric mission in artist's view

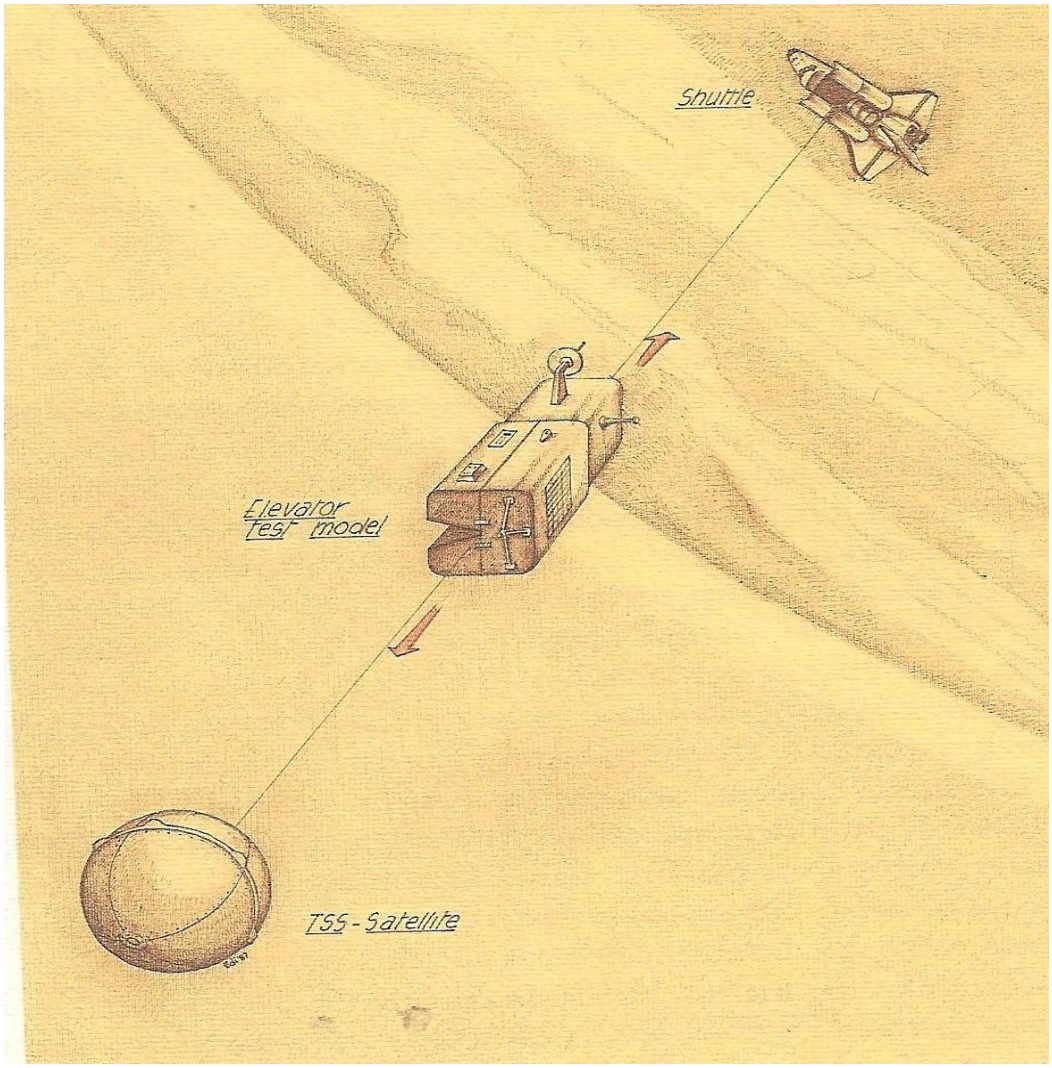


Fig 7 The " Elevator " mission scheme in an artist's impression